U.S. Military Use of Tourniquets from 2001 to 2010

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Abstract

Objective. This study was conducted to associate tourniquet use and survival in casualty care over a decade of war in order to provide evidence to emergency medical personnel for the implementation and efficacy of tourniquet use in a large trauma system. **Methods.** This survey is a retrospective review of data extracted from a trauma registry. The decade (2001–2010) outcome trend analysis of tourniquet use in the current wars was made in order to associate tourniquet use and survival in an observational cohort design. **Results.** Of 4,297 casualties with extremity trauma in the total study, 30% (1,272/4,297) had tourniquet use and 70% (3,025/4,297) did not. For all 4,297 casualties, the proportion of casualties with severe or critical extremity Abbreviated Injury Scales (AIS) increased during the years surveyed ($p < 0.0001$); the mean annual Injury Severity Score (ISS) rose from 13 to 21. Tourniquet use increased during the decade by almost tenfold from 4 to nearly 40% ($p < 0.0001$). Survival for casualties with isolated extremity injury varied by injury severity; the survival rate for AIS 3 (serious) was 98%, the rate for AIS 4 (severe) was 76%, and the rate for AIS 5 (critical) was 0%. Survival rates increased for casualties with injuries amenable to tourniquets but decreased for extremity injuries too proximal for tourniquets. **Conclusions.** Average injury severity increased during the decade of war for casualties with extremity injury. Both tourniquet use rates and casualty survival rates rose when injuries were amenable to tourniquets.

Key words: emergency medical services; resuscitation; shock; first aid; medical device

PREHOSPITAL EMERGENCY CARE 2014;Early Online:1–7

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This project was funded with internal USAISR funds, and the Defense Health Program (Proposal 201105: Operational system management and post-market surveillance of hemorrhage control devices used in medical care of U.S. servicepersons in the current war).

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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doi: 10.3109/10903127.2014.964892

Introduction

Boston's deadly marathon bombing on April 19, 2013, publicly showed the lifesaving need for emergency tourniquets to stop bleeding after major limb trauma. Survival rates of casualties have been improved for battlefield casualties when a first responder can control hemorrhage from an extremity wound with the use of an out-of-hospital tourniquet.[1,2] Tourniquet evidence gathered over the past decade has helped cause a sea change in tourniquet use from a means of last resort to a means of first aid.[1–6] Several reports have addressed tourniquet topics like device performance, indications for use, or survival outcomes.[1–6] Knowledge gaps remain, however. For example, the severity of the limb injury has not been clearly associated with survival rates in the setting of tourniquet use. Specific knowledge gaps exist for the extremity Abbreviated Injury Scale (AIS), which ranges from 1 (minimal), to 5 (critical). Trending a decade of tourniquet use rates with survival rates in the current wars could inform users, medics, and trainers on tourniquet indications, requirement and use rates, and effectiveness by injury severity. Filling such knowledge gaps is aimed at improving tourniquet training for users as it deals with indications for use, a current controversy.[6] Such gap fills may be referents for civilian trauma systems.[7,8] Past gap fills for prehospital tourniquet use have included successful hemorrhage control, prevention of hemorrhagic shock onset, and improved survival.[1–4] Awareness has increased of the utility of tourniquets in civilian tactical situations, mass casualty events, or multiply injured casualties in need of concurrent lifesaving interventions.[1–8]

The purpose of the present study is to associate tourniquet use and survival in casualty care over a

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 OCT 2014**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **U.S. Military Use of Tourniquets from 2001 to 2010**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Kragh J. F., Dubick M. A., Aden J. K., McKeague A. L., Rasmussen T. E., Baer D. G., Blackbourne L. H.,**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Army Institute of Surgical Research, JBSA Fort Sam Hosuton, TX**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

decade in order to provide evidence to emergency medical personnel for the implementation and efficacy of tourniquet use in a large trauma system.

METHODS

De-identified data extracted from the Department of Defense Trauma Registry were retrospectively reviewed. The protocol was reviewed by the U.S. Army Medical Research and Materiel Command's institutional review board, which determined that the protocol did not comprise research involving human subjects. The 10-year outcome trend analysis of tourniquet use in the current wars was made in order to associate tourniquet use and survival. An observational cohort design was made with subgroup analyses of survivors, nonsurvivors, those casualties with tourniquets used, and those casualties without tourniquets used. The review queried U.S. military registrants, i.e., active-duty casualties at any U.S. military hospital in either Afghanistan or Iraq. For a case to be included, major limb trauma was required such that the extremity Abbreviated Injury Scale (AIS) severity suffix was 3 or higher (Table 1). The AIS has a suffix after the diagnostic code, and the suffix is a whole number indicating severity of the threat to life from the injury; each coded injury within each of the six body regions has a suffix of varied severity. Or to be included, the extremity AIS could be 1 to 5 if paired with an associated *external* AIS of 3 or higher (Table 1); for example, if a severe burn of the skin overlaid a tibia fracture, then the two AIS codes would be associated. For the extremity or pelvic girdle body region, the AIS ranges from 1 to 5 as there are no untreatable (Score 6) extremity wounds.

The study period was September 11, 2001 to December 31, 2010. The data set had 4,297 casualties, of which 1,272 were in the study group (had tourniquet use recorded) and 3,025 were in the comparison group (no tourniquet use recorded). Nonsurvival was defined in the registry as death during hospitalization irrespective of the location of the hospital or the length of hospitalization; hence, prehospital deaths were not included in the registry.

Tourniquet use in the registry was yes–no data. The term *tourniquet indication* was used as a clinical sign available at the point-of-injury in deciding tourniquet use; this innate definition operationally meant in the present study that AIS was used. However, the closely related term, *tourniquet requirement*, was used in counting casualties in necessity of tourniquet use after the fact from existing data in the registry. *Indication* was a clinical term relevant to the decision-making about individual patients; *requirement* was a research term relevant to the epidemiology of public health. Measures of tourniquet requirement were defined in three ways: 1) casualities receiving a tourniquet expressed as a percentage of the total casualities with extremity trauma; 2) percentage of casualities with isolated limb exsanguination death without tourniquet use; and 3) percentage of casualities with limb and other body region exsanguination death without tourniquet use. The latter two percentages were identified as opportunities for improvement. The overall measure of tourniquet requirement was the sum of these three percentages.

TABLE 1. Casualty Injury Severity by Abbreviated Injury Scale Grades

Abbreviated Injury Scale Suffix	Injury Severity Description
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal (currently untreatable)

We collected the following data: age in years at time of injury, month and year of injury, gender, service, and AIS (2005 version) by maximum suffix (Table 1); only the maximum suffix of the AIS-coded injuries within each body region were analyzed. The analysis of a body region that was uninjured was done by using a suffix of 0 for uninjured body regions. We also collected Injury Severity Score (ISS) and death or survival outcome. ISS is a measure of degree of trauma of an individual casualty and is calculated from AIS values.

Descriptive statistics were used to portray the groups. For AIS proportions, survival and tourniquet rates and linear regression analyses were conducted using SAS (SAS Institute Cary, NC) and the associated PROC REG program that computed slopes (b) and intercepts and tested for their significance. Slopes were compared via analysis of covariance procedures (PROC GLM). Trend analyses were conducted using PROC FREQ and the associated Cochran-Armitage trend test and MS Excel 2003 (Microsoft, Redmond, WA). The ISS trend was analyzed by analysis of variance (ANOVA). A $p < 0.05$ was considered statistically significant.

RESULTS

Demographic Data of the Study (tourniquet) and Comparison (no tourniquet) Groups

Of the 4,297 casualties in the total study, 30% (1,272) had tourniquet use and 70% (3,025) did not (Table 2). Predictably, most casualties (96%, 4,120) were in the ground forces; i.e., Army or Marine Corps. Few casualties (2%, 99) were female. Iraq had more casualties (74%, 3,186) than Afghanistan (26%, 1,111). The median age of the casualties was 24 years, and ages ranged from 18 to 60 years.

TABLE 2. Casualty Demographic Data Including Study and Comparison Groups

Demographic Data	Study Group Tourniquet N* (Male, Female)	Comparison Group No Tourniquet N (Male, Female)	Total N (Male, Female)
Casualty count	1272 (1250, 22)	3025 (2948, 77)	4297 (4198, 99)
Army	916 (895, 21)	2276 (2213, 63)	3192 (3108, 84)
Marine Corps	316 (315, 1)	612 (608, 4)	928 (923, 5)
Navy	25 (25, 0)	76 (72, 4)	101 (97, 4)
Air Force	15 (15, 0)	61 (55, 6)	76 (70, 6)
Afghanistan	375 (373, 2)	736 (723, 13)	1111 (1096, 15)
Iraq	897 (877, 20)	2289 (2225, 64)	3186 (3102, 84)
Survival	1170 (1151, 19)	2913 (2839, 74)	4083 (3990, 93)
Death	102 (99, 3)	112 (109, 3)	214 (208, 6)

*N = casualty count.

All 4,297 casualties had some form of extremity injury with an indication for tourniquet use. Injury severities reached a maximum in 2010 (Figure 1). The mean and median ISS for the 4,297 casualties of the whole data set increased over time (p <0.0001), whereas a mode of 10 occurred in each year. The proportion of casualties with a severe or critical extremity injury increased annually in 7 of 8 years (Cochran-Armitage $p = 0.027$) (Figure 1).

Tourniquet Rates over a Decade of War

Tourniquet use rates rose from 4 to nearly 40% over a decade for the whole data set ($p < 0.0001$, Figure 2). Tourniquet use rates for casualties with extremity injuries were low in the beginning of the war when tourniquets were less available and their use was uncommon, but rates soon increased. Furthermore, tourniquet use rates for serious and severe injuries increased over a decade (Figure 3). Use rates were low at the beginning of the war (2002) when tourniquets were less available and their use was uncommon, but annual rates soon increased asymptotically (Figure 3). For the initial 5 years (2002–2006), tourniquet use increased ($p \leq 0.03$) for both severe and serious injuries. Moreover, speed of implementation of tourniquet use was threefold greater for severe vs. serious injuries ($p = 0.004$). Between 2006 and 2010, use rates did not change ($p > 0.05$) for either severe or serious injuries, but rather plateaued

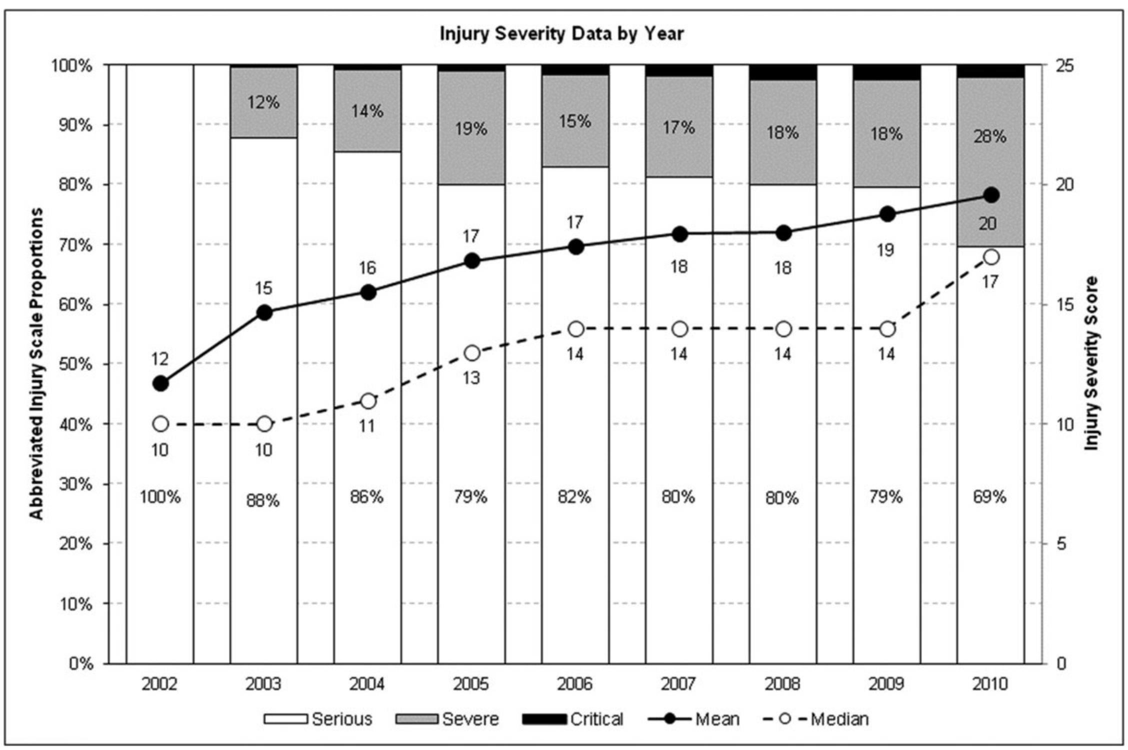

FIGURE 1. Injury severity data by year. (A) Injury Severities Scores by calendar year for the 4,297 casualties that had extremity injuries. Extremity Abbreviated Injury Scale: serious (suffix 3, white columns); severe (suffix 4, gray columns); and critical (suffix 5, black columns). (B) Injury Severity Scores represented by mean (black line and circle) and median (black dashed line and white circle).

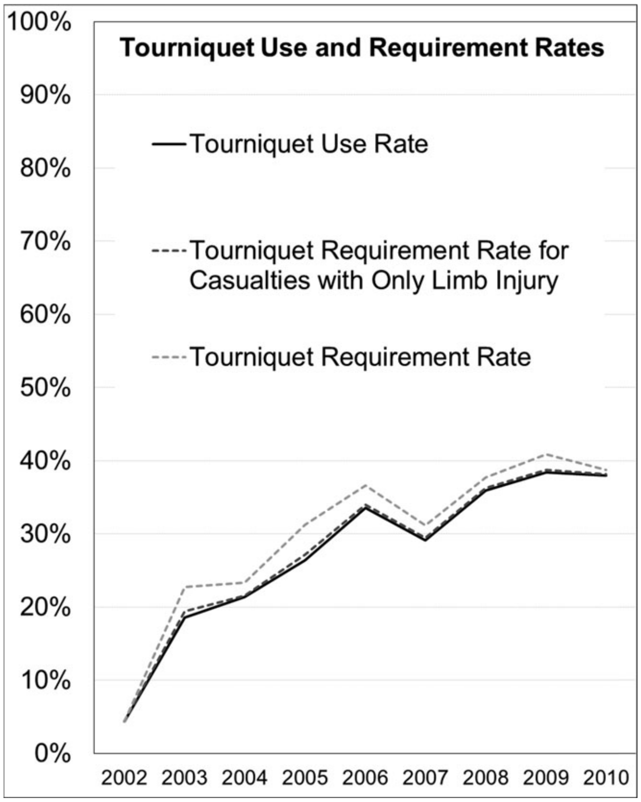

FIGURE 2. Annual tourniquet use and requirement rates for the 4,297 casualties that had some form of extremity injury. The Tourniquet Use Rate (numerator as the annual number of casualties that had tourniquet use; the denominator was all casualties analyzed for that year). As a measure of additional requirement of a tourniquet was the Requirement Rate for Casualties who died without tourniquet used while having only limb injury and no other body region injured. The Requirement Rate for Casualties with only limb injury is only marginally more than the Tourniquet Use Rate since the number of casualties with isolated limb exsanguination death without a tourniquet used was 17 for the study period. As a measure of additional requirement a tourniquet was the Tourniquet Requirement Rate as the overall sum of the Tourniquet Use Rate, the Requirement Rate for Casualties with only limb injury, and the Requirement Rate for Casualties with limb injury and at least another body region injured who died without tourniquet use. Not every extremity injury indicated tourniquet use so the annual rates do not sum to 100%.

at an approximate twofold greater use for severe injuries.

Like tourniquet use rates, tourniquet requirement rates also increased (Cochran-Armitage $p < 0.0001$) during the survey for the whole data set (Figure 2). The first was the tourniquet requirement rate for casualties with only limb injury (all died of isolated limb exsanguination) was smallest, but it was zero only in 2002 (indicated use without use of the tourniquet for a death). The second was the rate of tourniquet use. The third was the tourniquet requirement rate for casualties with limb injury and at least another body region injured who died without tourniquet use. The overall measure of tourniquet requirement as the sum of three rates increased almost tenfold during the study from 4% in 2002 to 39% in 2010.

Survival Analysis

The survival rate of casualties in the whole data set was 95% (4,083/4,297; 95% for males and 94% for females). Associations among individual military services and operation (Iraq and Afghanistan) for gender survival were not statistically significant, but the rate of tourniquet use for females in Afghanistan was lower than the rate for males in Afghanistan (13.3 and 34%, respectively; $p = 0.0461$). Survival rates with tourniquet use (study group, 1,272 casualties) increased $p = 0.02$) from 2004 to 2010 as did annual mean ISSs (Figure 4). Despite the increased injury severity, the survival rate increased. The year 2002 was exceptional because it had only 23 casualties, all of which had extremity AIS values of only 3 and were not analyzed. All other years had more casualties with a wider range of injury severities. The annual mean ISSs showed an increase that was statistically significant (linear regression slope, 0.8903, $R^2 = 0.7999$).

When survival was evaluated with or without tourniquet use, the result was as expected given prior similar experience.[8] For the casualties with tourniquet use and with no tourniquet use (Table 2), the survival rate of those with tourniquet use (92%, 1,170/1,272) was lower than that of those with no tourniquet use (96%, 2,913/3,025, $p < 0.0001$).

The survival rate for casualties with isolated extremity injury was 96% (578/603) whether tourniquets were used or not. However, survival rates varied by the severity of their extremity injury: serious 98% (550/563), severe 76% (28/37), and critical 0% (0/3). Survival rates also varied by casualty extremity AIS with or without injury of other body regions; the survival rate was 100% for minor extremity injury, 96% for moderate and serious extremity injury, 91% for severe extremity injury, and 71% for critical extremity injury.

Although the survival rate for casualties overall was 95% (4,083/4,297), whether a tourniquet was used or not, survival rates varied by casualty extremity injury severity with or without other body regions injured. The survival rate for casualties with minor extremity injuries was 100% (1/1), with moderate extremity injuries was 96% (23/24), with serious extremity injuries was 96% (3,326/3,456), with severe extremity injuries was 91% (688/753), and with critical extremity injuries was 71% (45/63).

Critical injuries are a minority of all extremity injuries and appear to differ in their response to tourniquet use from those extremity injuries that were less severe (Figure 1). Survival rates for casualties with tourniquetable extremity injury (either serious or severe) trended in the opposite direction than nontourniquetable critical extremity injury. Because serious or severe extremity injuries are amenable in general to tourniquet use, as they are generally distal on the limb where tourniquets fit, their survival rates were both

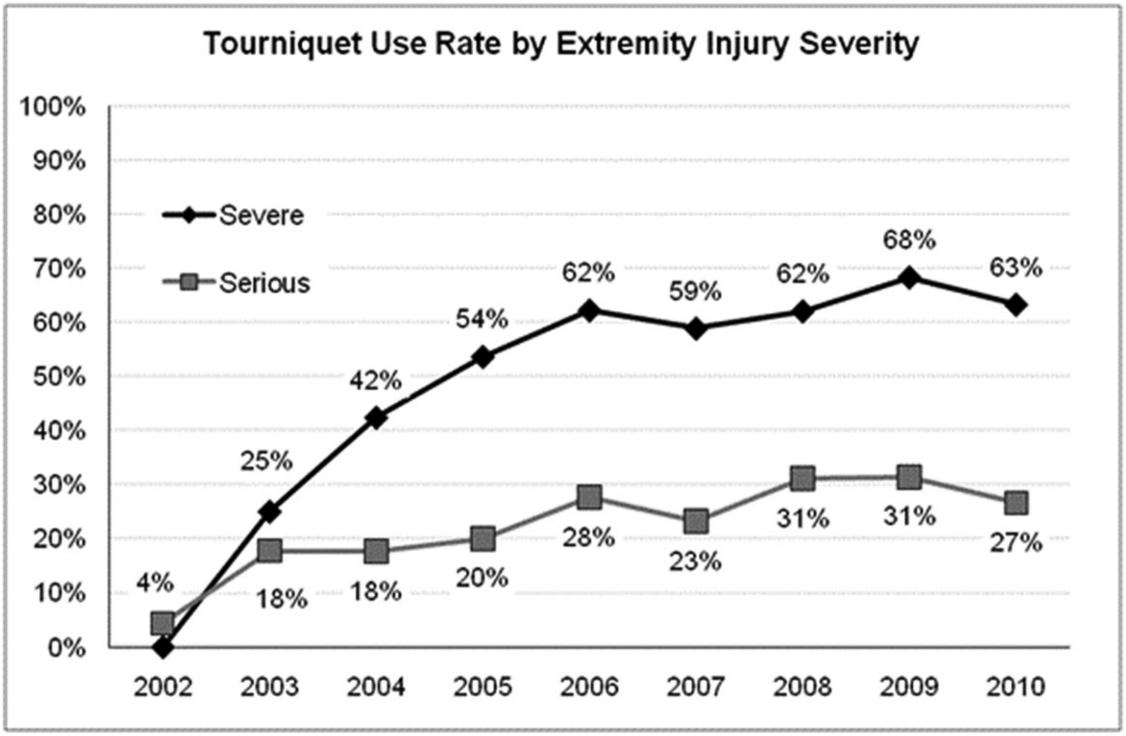

FIGURE 3. Tourniquet Use Rate by year for casualties who had serious and severe extremity injuries. Among the 4,297 casualties studied, 753 had severe extremity injury and 3,456 had serious extremity injury.

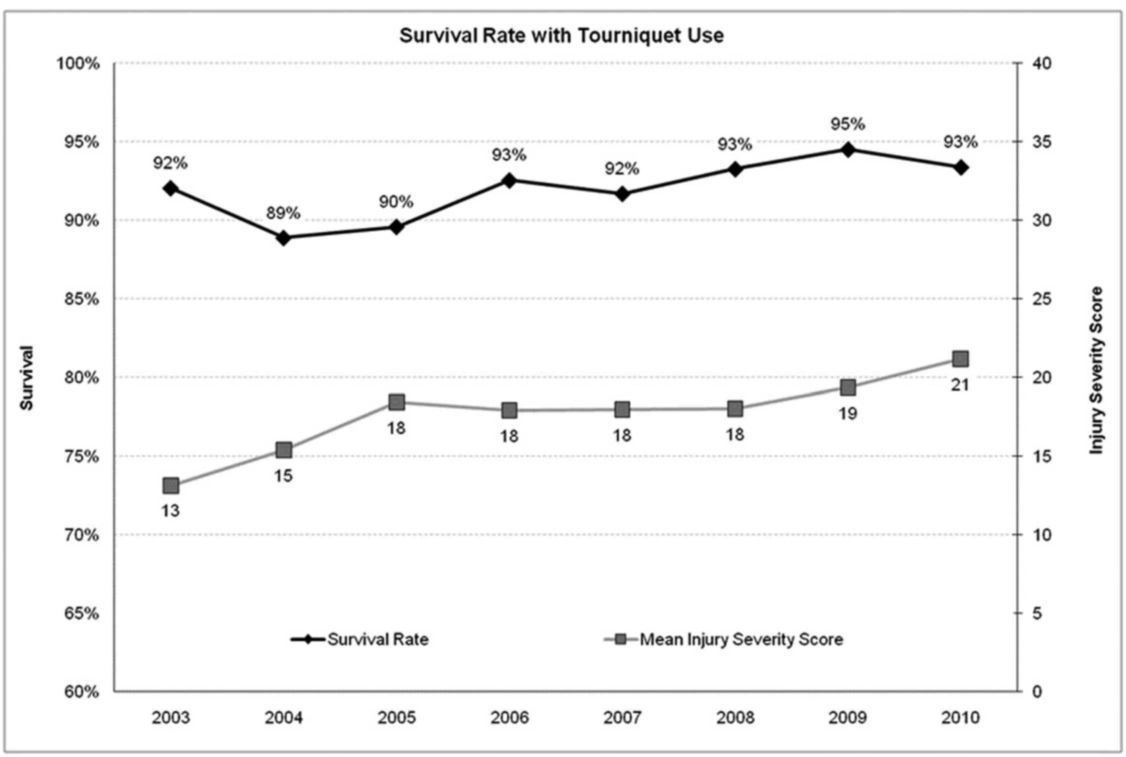

FIGURE 4. Survival rates for all Abbreviated Injury Scales for those 1,272 casualties for which tourniquets were used and associated Injury Severity Scores (ISS) for each year.

high and increased over time whether or not the casualty had a tourniquet (slope = 0.0042, $R^2 = 0.4556$; $p = 0.028$). In nontourniquetable, critical extremity injuries, which were proximal and where tourniquets cannot fit, however, survival rates were low and did not change over time whether or not the casualty had a tourniquet (slope = -0.0354, $R^2 = 0.3315$; $p > 0.05$).

Discussion

The main finding of the present survey indicates associations between the tourniquet use rate and the survival rate. The annual tourniquet use rate rose, and the annual survival rate of casualties with injuries amenable to tourniquet use rose concurrently. At the same time, survival rate decreased for those casualties with injuries that were not amenable to tourniquet use. For injuries amenable to tourniquet use, the military trauma system improved some outcomes, like survival in difficult circumstances on the battlefield.[7] Tourniquet use increased during the decade almost tenfold, 4 vs. ∼40%.

Two minor findings of the present survey dealt with medical training. First, the evidence indicated that tourniquet use was a better indicator of threat to life than the AIS suffix, likely because users directly see exsanguination in real time, which is more meaningful than clerical coding of injury severity after the fact. This first finding implies that users can discern the requirement for hemorrhage control. Second, tourniquet use and requirement rates are useful information for emergency medical trainers that can readily be used for instructional purposes. Interestingly, the rates paralleled each other closely over the years examined. In addition, the isolated limb injury survival rates by extremity injury severity ranged from 100% with minor injuries to 71% for critical extremity injuries. Initial hospital triage by a person who can identify such injury severities and their associated general survival rates in modern trauma may find this knowledge useful in triage.

The present survey evidences extremity injury severity and tourniquet use in new ways. Critical extremity injury in the present survey is limited to those about the skeletal pelvis and hip, where no regular tourniquet can fit; these injuries are not amenable to tourniquets because they occur at the junction of the trunk and limbs. However, using critical to mean *junctional* limits junctional to its most severe form. Serious and severe injury are commonly amenable to tourniquets, but some of these injuries are junctional and not amenable to tourniquets; such categorization is a simple but crude method suitable for a broad understanding, such as in an overview study of a decade of casualty data from a registry. The comparison of survival rate of tourniquetable extremity injury to nontourniquetable extremity injury indicated that tourniquets were well used for suitable, distal injuries while fielded junctional injury treatments are currently suboptimal. Currently, junctional injury treatments in the field, like hemostatic dressings, may not be sufficient by themselves for junctional hemorrhage control.

Strengths of the present survey center on its size, duration, and breadth. The number of casualties with tourniquets is the largest reported to date, the duration of the survey is the longest reported, and the breadth of the data is wide demographically. We have previously covered several tourniquet topics in depth; so this broad survey was designed and conducted to complement prior work without redundancy. In reporting the largest tourniquet survey, the present study can increase awareness of practical hemorrhage control of extremity trauma as an adjunct to resuscitation in emergency medical care.

Limitations of the present report are numerous. Retrospective surveys of trauma care data are not controlled experiments; association is not causation. Observations are limited to registry data available; care records in war have little data to code and thus data depth is shallow. Codes were given after admission, but the tourniquet user assessed major limb bleeding prehospital without knowledge of, or regard to, any future code. By definition and procedure, trauma registrants arrive alive at a hospital, and casualties killed prior, or who arrive without vital signs (and are not regained), are excluded. Such exclusions bias the data and interpretations to those least in requirement of tourniquets. Limb salvage and other limb outcomes of interest are not in the registry. AIS is a threat-to-life score, the only surrogate of hemorrhage control requirement available. AIS 3 (serious) can be either a sciatic nerve laceration or a traumatic below-knee amputation. One may indicate a tourniquet; the other may not, although AIS severities are identical. Only broad findings can be made from such a crude surrogate, and surveys of large cohorts of casualties are epidemiologic study of public health more so than scrutiny of care of individual casualties. Indication is not recorded, so it can be inferred weakly from AIS.[8] Tourniquet use itself strongly indicates threat to life, and as such tourniquet use may indicate threat to life better than the Abbreviated Injury Scale. However, AIS is a weaker threat-to-life index; so survival by AIS with tourniquets is lower than without.[8]

Future directions for research are several. Statistical matching of registrants, such as in propensity matching, may further explore associations among survival, injury severity, and tourniquet use. Users at the point of injury or providers thereafter may indicate tourniquet use for observed bleeding or situations such as care under fire, but registries are currently absent such data. Health-care disparities for females in Afghanistan with extremity injuries should spur new research.[9]

CONCLUSIONS

In summary, the present survey of war casualties with extremity injury shows that survival rates are increased in those casualties with injuries amenable to tourniquet use, despite an increased injury severity. The findings of the present study are 1) tourniquet use rates have risen in recent years; 2), survival rates of those casualties with injuries amenable to tourniquet use rose concurrently; 3) those with injuries that were not amenable to tourniquet use decreased; and 4) tourniquet requirement rates are opportunities for improvement. This new knowledge supports the following recommendations:

- Use extremity injury survival rates to aid initial hospital triage.
- Require tourniquet trainers to instruct students on the requirement rates.
- Implement a junctional bleeding solution.
- Use this study as a template for similar studies concerning torso hemorrhage or airway first aid.

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